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PROPOSED METHODS OF REDUCING THE CABLE LOAD AND TENSION OF HIGH-SPEED TOWING TARGETS

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PROPOSED METHODS OF REDUCING THE CABLE LOAD AND TENSION OF HIGH-SPEED TOWING TARGETS

SUMMARY

The present report analyzes the inter-relationship between the drag of a target and certain properties of the towing cable, namely, its diameter, length, weight, drag, tension and load. As a result of the analysis, a method of towing is proposed by which overall cable tension and cable load on a target can be reduced to such an extent that:

a. The present G-60 Target can be towed with 7,000 feet of towline at 30 knots. This is a considerable improvement over the present maximum speed of about 20 knots with this length of towline.

b. The risk of casualty is reduced.

c. A new design of towing target is feasible with a displacement more in proportion to the useful load carried and representing a large saving in target weight and cable material.

The report also examines the changes in cable tensions and cable loads which take place during a 180 degree turn. A method of turning is proposed which produces practically no change in cable tension and cable loads, and by which a turn can be made in approximately one-third of the time presently required.

INTRODUCTION

At present, the breaking of towing cables during target practice results in considerable inconvenience and expense. Due to erratic behavior of the target, the cable tension at the towing vessel often exceeds the yield strength of the cable, even at slow speeds. The strength of the cable is, at present, the factor which limits the maximum speed of operation to about 20 knots. Unfortunately the strength of cable cannot be sufficiently increased by use of larger wire sizes as this would limit too severely the maximum length of cable that can be handled by existing winches on the towing vessels.

The demand for higher speed, and especially for greater distance between the towing vessel and the target, has resulted in greatly increased cable load on the target as well as cable tension. This demand, in turn, has lead to a gradual increase in the size of target from the original one of 25-foot length

to the present G-60 target of 60-foot length. The 150,000 pounds displacement of the latter is out of porportion to the few thousand pounds of useful load carried. In addition this target has a tendency to nose dive and capsize in service (1)*

In an attempt to reduce cable tension and improve the towing characteristics of targets, the David Taylor Model Basin, at the request of the Bureau of Ships (2), conducted tests on a group of five models, of which four represent new designs and one represents the G-60 target.

These tests (3) lead to the conclusion that cable drag, target stability, and target maneuverability are the fundamental factors in the design of a target with improved towing characteristics. The target drag itself is of secondary importance.

The purpose of this report is to analyze the present methods used for towing targets, and to propose means by which the cable tension and overall performance of targets can be improved.

The first section of the report deals briefly with some towing characteristics of the G-60 target sled. In subsequent sections the factors affecting cable tensions and cable loads are discussed and methods of reducing these are proposed. The manner of making a simple 90-degree turn is illustrated and the difficulties that may arise from abrupt changes in cable tensions and cable load are discussed. A method of turning is illustrated whereby these difficulties are minimized. The last section of the report concerns a proposed new design which was developed in the light of the knowledge gained from these studies.

CHARACTERISTICS OF THE G-60 TARGET SLED

The G-60 target sled has a 25-foot beam, a 60-foot length, and a displacement of about 150,000 pounds. As a large number of targets of this type are on hand, it is important to devise methods by which their towing performance can be improved, i.e. means of increasing the maximum speed and decreasing the number of casualties.

The casualties, which often happen at slow speeds, manifest themselves in nose diving and capsizing or in a combination of both. By reason of its construction this target cannot be trimmed to give best results at low speeds without adding greatly to the total weight. According to Reference (1) some

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* Numbers in parentheses indicate references at end of this report.

improvement has been obtained in service by adding about 14000 pounds of ballast at the stern of the target. Perhaps the most important factor contributing to casualties with this design is the large cable load which, at all speeds, is imposed upon the target. As the towpoint is located well forward of the transom, even a partial elimination of this load will reduce the number of casualties.

The term "cable load" is used for the downward component of the pull from the towline on the target, and is a function of the target drag, D, and the "cable angle", φ. The term cable-angle is used for the angle between the cable and the horizontal plane at the target towpoint. The cable load ($D \cdot \tan \varphi$) must not be confused with the cable tension at the target, which is also a function of the cable angle, but is $D \cdot \sec \varphi$.

Before focusing attention on the reduction of cable load, the possibilities of increasing the maximum speed should be examined, not only because higher speeds are demanded, but also because the towing characteristics of a planing hull improve with speed.

We may state the problem to be that of towing the G-60 target at a speed of 30 knots with 7,000 feet of towline, using the smallest diameter cable consistent with the strength required. To this end a knowledge of the maximum cable tension and cable load on the target is necessary.

The cable tension will always be a maximum at the towing vessel, because at this point the drag of the entire length of the towline is imposed upon the cable. As the angle of the towline with the horizontal at the towing vessel is small at high speeds, the maximum cable tension is practically the same as the horizontal drag of the towline at the towing vessel. This horizontal drag is, obviously the drag of the target plus the drag of the towline.

The data on cable tensions and cable loads produced by the G-60 target when towed at different speeds and with different lengths of 1-inch diameter cables are available from Reference (3) and are reproduced in this report with their original texts and Figure numbers.

30 Knots - 1-Inch Cable

From Figure 23, it is seen that the G-60 target can not be towed at 30 knots with 7,000 feet of 1-inch cable without exceeding the yield strength of this cable.

30 Knots - 1-3/8 Inch Cable

The cable tensions and cable loads for successively larger cable sizes were calculated by the methods presented in Appendix 1. It was found that 1-3/8 diameter cable was the smallest which could be used without exceeding the yield strength.

The cable load (33,000 pounds) and the maximum cable tension (119,000 pounds) for this size cable are shown in Figure 1a. The cable material (25,100 pounds or 127,600 cubic inches) is beyond the capacity of the present winches. Because new and larger winches are not comtemplated, and because of the added difficulty of handling this large cable, not to mention the excessive cable load on the target, towing with this size cable is considered impractical.

Figure 1a shows, however, that the weight of the towline can be reduced, because the 1-3/8 inch cable is stronger than necessary for the tensions adjacent to the target. The fact that the tensions increase steadily along the towline towards the towing vessel, suggests that instead of using a towline of constant diameter, the towline be made up of different lengths of cables, each of the smallest possible diameter consistant with the strength required at its location. Such a tapered towline would meet the strength requirements, and effect an appreciable saving in weight. Since towing cables are not manufactured in lengths of 7,000 feet, but are made up of shorter lengths, the process of tapering the towline adds only a small complication.

30 Knots - Tapered Towline

In Figure 1b, the 1-3/8 inch cable has been replaced by a tapered towline thereby affecting a reduction of maximum cable tension from 119,000 to 83,400 pounds and a reduction of cable load from 33,000 to 20,600 pounds. Although a tapered towline results in a large reduction in cable load, it is believed that a cable load of 20,600 pounds will interfere with the maneuverability of the target (explained in detail in Appendix 2). Other means must be found leading to a further reduction of this load.

Examining Figure 1b it is seen that the reductions in cable load and tension are principally due to reductions in cable drag and cable angle. Inasmuch as cable load, cable drag and maximum cable tension, are functions of the cable angle (the form drag of a cable perpendicular to stream is 50 times greater than its frictional drag), the importance of reducing the cable angle becomes evident. In fact, reducing the cable angle will result in a chain of benefits because reduction of cable drag will in turn reduce the cable angle.

As further reduction in cable size cannot be made without overstressing the towline, the only other way, short of redesigning the target, appears to be the introduction of a carrier or float, between the towing vessel and the target. Because

only that length of towline between the target and the cable-carrier can affect the cable angle at the target, the cable-carrier will produce the same effect as a reduction in the overall length of towline.

30 Knots - With Cable Carrier

Figure 1c shows a cable-carrier introduced at a point 3,000 feet from the target. Compared with Figure 1b the cable angle has been reduced from 37 to 6 degrees and the cable load from 20,600 to 2,200 pounds, which is practically constant for all speeds. (See Figure 32 reproduced from Reference (3)). The cable tension at the target has been reduced from 34,200 to 22,200 pounds, so that the tapered towline can start with 3/4 inch cable and need not increase beyond 1-1/8 inch diameter, because the tension at the towing vessel has been reduced from 83,600 to 72,600 pounds. The volume of the towline is now 59,340 in lieu of 71,900 cubic inches, thus allowing a winch of smaller capacity.

10 Knots - Without a Cable-Carrier

Since casualties often happen at slow speeds, it is of interest to examine the cable angle and load at a low speed, say 10 knots. Without the cable-carrier and with a constant diameter towline, Figure 2a, the cable angle is 64 degrees and the cable load 20,500 pounds. By tapering the towline, Figure 2b, the cable angle and load are reduced to 55 degrees and 13,200 pounds. Experience indicates, however, that these values are unacceptably high. High cable loads and angles have a detrimental effect on the maneuverability of the target at low speeds (see Appendix 2).

10 Knots With Cable-Carrier

By employing a cable-carrier, Figure 2c, the cable angle is reduced from 55 to 14 degrees, and the cable load from 13,200 to 2,300 pounds. One may consequently conclude that a cable-carrier will improve the general performance of the G-60 target both at high and low speeds. If it is kept reasonably small it should not complicate towing procedure too much.

The TMB-Design of Cable-Carrier

Figure 3a shows a TMB-Design of a 20-foot cable carrier with a constant beam of 8 feet, weighing about 3,000 pounds. It is a craft whose planing surface has lines similar to those of the TMB-60 target, which was found to be stable at all

model speeds up to the highest speed tested, corresponding to 70 knots full scale ($V/\sqrt{L} = 9$). The small size of the cable-carrier is compensated by its ability to travel through breakers, or to nose upward with a large lift-drag ratio, should it momentarily become submerged. The resistance of the cables to being swished up and down in the water will dampen pitching in heavy weather. The hull is symmetrical both in the vertical and the lateral planes, and all of its surfaces are developable from flat plates.

Two towpoints are shown, either of which can be used. If, to facilitate handling, the topside one is used, the cable-carrier will turn over when the towline has sufficient length, and from then on travel in normal running condition.

Figure 3b shows a method of streaming and retrieving a target when a cable-carrier is employed. This method requires no additional equipment, but may consume some additional time.

The effect of the cable-carrier on the maneuverability of the target and in turns is explained in detail in Appendix 2.

Characteristics of the Bureau of Ship's (A) Design and the TMB-60 Design of High Speed Towing Targets.

Models of these designs were tested during the spring of 1947 at the Taylor Model Basin (3). They are both 60-foot targets and have the same displacement, but differ in design. The BuShip's design is a boat-type target, modeled after the PT-Boats and has a maximum beam of 22-½ feet, while the TMB target is of the sled type, and has a constant beam of 25 feet. The TMB-60 is designed to be towed by a single cable from a point on the keel-line, at the longitudinal center of flotation (which is close to the high speed center of dynamic pressures), while the BuShip's Design uses the conventional bridle attached to the two chines about 42 feet forward of the transom.

30 Knots - 1-Inch Cable

As shown by Figures 26 and 30, neither of these targets can be towed at 30 knots with 7,000 feet of 1-inch cable without exceeding the yield strength of the cable.

30 Knots - 1-3/8-Inch Cable

Since these designs have about the same drag at 30 knots, the values of cable tensions and cable load for both can be illustrated by Figure 4a, which shows the targets towed with 7,000 feet of 1-3/8 inch cable, the smallest size of sufficient

strength.

30 Knots - Tapered Towline

When the 1-3/8 inch cable is replaced with a tapered towline, Figure 4b, the maximum cable tension is reduced from 121,000 to 71,300 pounds and the cable load from 39,000 to 21,800 pounds. The volume of the towline is reduced from 127,600 to 61,600 cubic inches.

The advantage of the tapered cable is better demonstrated by these designs than by the G-60 design. Their smaller target drag produces a smaller cable tension at the target, which permits the taper of the towline to start with a smaller diameter, thus reducing the cable weight and drag. However for the same size towline of constant diameter the smaller drag of these targets produces a greater sag of the towline than obtained with the G-60 target, which increases the cable drag, and may in the end produce a larger cable tension at the towing vessel.

30 Knots - With Cable-Carrier

Figure 4c shows that at 30 knots a cable-carrier will reduce the maximum cable tension of the BuShip's Design (A) and the TMB-60 from 71,300 to 50,800 pounds and the cable load from 21,800 to 1,400 pounds. The cable volume is reduced from 61,600 to 38,100 cubic inches, thus allowing a winch of smaller capacity.

10 Knots - Without Cable-Carrier

Figures 5a and 5b show the values of cable angles and loads for these designs when towed at 10 knots with 7,000 feet of constant diameter cable, and with a tapered towline. It is seen that they differ in performance in that the cable angle of the BuShips' design is much larger than that of the TMB-Design. The better performance of the TMB-60 is due to its high drag at low speeds. At 10 knots the drag of the TMB-60 is more than double that of the BuShips' design.

10 Knots - With Cable-Carrier

When towed at 10 knots with a cable-carrier, Figure 5c, the cable angle of the BuShip's design is reduced to 31 degrees, and the cable load from 13,500 to 1,400 pounds, while the cable angle of the TMB-60 is reduced to 13 degrees and the cable load from 12,200 to 1,200 pounds.

The high cable loads carried by these designs can be practically eliminated by employing a cable-carrier. It seems, however, out of reason to build a new target of large dimensions and specifically designed to carry a maximum load of about 40,000 pounds at its towpoint, and then employ a cable-carrier to eliminate this load. In other words, one of the advantages of a cable-carrier is that it makes it possible to use a target, designed to carry the necessary screen load, instead of a target which has to be designed for the large cable load encountered in the present method of towing.

New Target Design: TMB-50

In designing a high speed towing target, the principal object should be a hull which can be towed at all speeds with a minimum of casualties caused by erratic behavior of the hull. Initial cost of construction should be secondary to performance because the expense in delays and damage done by just one casualty may exceed any savings in the initial cost of construction. With this in mind, the hull-lines of TMB-50 were designed to have maximum dynamic stability in all directions. All of the surfaces are either flat plates or developed cones inexpensive to construct and repair, but chosen primarily because it is believed they produce the most favorable hull lines for a target to be steered by a towline.

Figure 6a shows a 50-foot target with a constant beam of 16 feet and a displacement of about 30,000 pounds. The hull-lines are similar to those of the TMB-60 target, but are specifically designed to be towed by a cable-carrier, or in lieu thereof by a single unsupported towline of length not to exceed 4,000 feet. Its principal features are briefly:

a. Highly developed longitudinal, lateral, and directional stability.
b. Ability to swing its bow quickly, even from a stand still, towards a new direction of the towline, without water piling up at the chine.
c. Similar to the TMB-60, its hull-lines produce comparatively high drag at low speeds, and low drag at high speeds.

In contrast to the TMB-60 target, which was designed to carry a maximum cable load of 40,000 pounds at its towpoint, the towpoint of the TMB-50 is located well forward of the transom. Maneuverability is therefore improved, and sail drift reduced, see Appendix 2.

Figure 6b shows the values of maximum cable tension (39,800 pounds) and cable load (800 pounds) for this target produced at

30 knots, when towed with cable-carrier and 7,000 feet of towline.

Appendix 3 gives a comparison of the G-60, TMB-60, and TMB-50 targets at a speed of 30 knots and with 7,000 feet of towline, when towed by the three methods discussed in this report.

IN CONCLUSION

The demand for greater distance between the towing vessel and the target has resulted in increased cable tensions which limit the maximum towing speed and increased cable loads on the target which cause casualties. This demand has also lead to a gradual increase in the size of target to the present G-60 target of 60-foot length and 150,000 pounds displacement.

Assuming that a speed of 30 knots is required and that 7,000 feet of towline satisfy the demand for distance between the towing vessel and the target, the advantages of the method of towing suggested in this report, can be judged by the following comparisons:

a. The maximum speed of targets is at present about 20 knots. The new method of towing raises this speed to 30 knots.
b. At present the maximum speed of 20 knots produces a cable load of 14,000 pounds, while the new method of towing produces only 2,200 pounds at 30 knots. (If this speed was feasible with the present method of towing, the cable load would be 33,000 pounds).
c. At present it takes about 13,230 pounds of cable material to tow at 20 knots, while with the new method it takes only about 12,200 pounds at 30 knots.
d. At present a speed of 20 knots produces a maximum cable tension of 58,000 pounds (119,000 pounds, if 30 knots was feasible with the present method of towing), while the new method produces 72,600 pounds at 30 knots.
e. The new target suggested in this report, when towed with a cable-carrier travels with a cable load of less than one thousand pounds at all speeds. It uses about 5,300 pounds of cable material at 30 knots, and effects a large saving in target weight, compared with either the G-60, BuShips Design (A) or TMB Design 60 targets.

REFERENCES

(1) History of sled-type towing targets with enclosed references prepared by BuShips, Structure and Form (443) dated 24 April 1947.

(2) BuShip's ltr QT-(3) (422-440) of 24 Feb 47 to TMB.

(3) Curry, J. H., and Posner, Jack, "Results of Experiments with Models of High-Speed Towing Targets Including Estimates of Full-Scale Target Drag and Cable Tension", TMB Report 595, November 1947.

(4) Posner, Jack, "Result of Additional Experiments with a Model of the Revised G-60 Sled-Type Towing Target", TMB Report 630, January 1948.

(5) Thews, J. G., and Landweber, L., "On the Resistance of a Heavy Flexible Cable for Towing a Surface Float behind a Ship," EMB Report 418, March 1936.

APPENDIX 1

Methods of Computing Cable Angles, Cable Loads, and Cable Tensions

When a cable of constant diameter is employed, the method used for determining the factors which influence target drag and cable angle, load, drag and tensions, is given in References (3) and (5). Substituting a tapered towline for the constant diameter towline employed in these references would require long and tedious computations, if all the factors were considered. In the computation of cable loads and cable tensions of tapered towlines in this report, only the more important factors involved are, therefore, included in the calculations.

Target Drag and Cable Angle

Figures 23, 26, 30, reproduced from Reference (3), show the values of target drag produced by the G-60 Design, the BuShip's Design A, and the TMB-60 Design, when towed with different lengths of cable of 1-inch constant diameter. Figure 32 shows the corresponding cable angles produced by these designs, when the target drag and length of cable are known. A formula is needed by which the length of a tapered towline can be reduced to a corresponding length of 1-inch diameter cable, in order that these charts may be used to find the target drag and, in consequence, the drag-length ratio of the target and the towline. Knowing this ratio the cable angle is given by Figure 32.

As weight and length of the cable are the most important factors influencing the cable angle, and because the other factors involved vary with weight and length, the following empirical formula was developed in which the less important factors are ignored. Computations by this formula agree closely enough for all practical purposes with the method used in Reference (3).

$$L_1 = L \cdot \frac{W}{1.80} [1 + 0.24 (1-12d)]$$

where:

- L is the length in feet of the cable to be computed,
- W is the weight in pounds per foot of the cable in salt water,
- 1.80 is the weight in pounds per foot of 1-inch cable in salt water,
- d is the diameter in feet of the cable to be computed ($12d$ is the dia. in inches),
- L_1 is the effective length.

Cable Load and Cable Tension at the Target

When the target drag D and the cable angle are known, the cable tension at the target is also known, since

$D \cdot \tan \varphi$ = cable load, and
$D \cdot \sec \varphi$ = cable tension at target

Drag of a Tapered Towline

The effective length (computed by the above formula) used to determine the target drag and the cable angle cannot be used in the same manner to determine the drag of the tapered towline, because the predominant factors influencing the drag are the wetted areasand the cable angle.

To facilitate the calculations of the drag of a tapered towline a chart, Figure 7, is shown which gives the drag in pounds per foot of different sizes of cables for cable angles varying from zero to 70 degrees. The cable drag at zero cable angle is given by $\frac{1.6}{50} \cdot \frac{\rho}{2} \cdot d \cdot V^2$ which is the tangential friction force in pounds per foot,

where,

$\frac{1.6}{50}$ is an arbitrary constant (the same for all sizes of stranded cables),
ρ is the mass density of water,
d is the cable diameter in feet (12d is the dia. in inches),
V is the speed in feet per second.

Cable Tension at Towing Vessel

The drag of the towline plus the drag of the target is the horizontal drag at the towing vessel. As the angle of the towline with the horizontal is always small at the towing vessel, the horizontal drag and the cable tension at this location are practically the same. The cable tension at the towing vessel is, of course, the maximum cable tension in the system.

Subtracting the cable tension at the target from the cable tension at the towing vessel and dividing by the length of the towline gives a fairly accurate picture of the increase in cable tension per foot along the length of the towline.

Sample calculations are given in examples (A) and (B).

Example A: A G-60 Target is towed at 30 knots with 7,000 feet of 1-3/8 inch constant diameter cable. Compute the values shown in Figure 1a.

$$L_1 = L \cdot \frac{W}{1.80} [1 + 0.24 (1-12d)]$$

1-3/8 cable; $W = 3.40$; $1 - 12d = - 3/8$, $L_1 = 12,010$ Feet

Target Drag = D = 33,000 pounds (by extrapolation of Figure 23)

$\frac{D}{L_1} = 2.75$

Cable Angle at target, φ = 45 Degeees (from Figure 32)
Cable Load = 33,000 x tan 45° = 33,000 pounds
Cable Tension at Target = 33,000 x sec 45° = 46,700 pounds
Drag of Towline = 7,000 x 12.3 = 86,000 pounds (from Figure 7)
Horizontal Drag at Towing Vessel = 33,000 + 86,000 = 119,000 Pounds (Virtually maximum cable tension)

Increase in cable tension along the towline = 10.33 pounds per foot.

Example B: A G-60 Target is towed at 30 knots with 7,000 feet of tapered towline. Compute the values shown in Figure 1b.

1800' of 7/8" Cable; W = 1.39; 1-12d = + 1/8; L_1 = 1,432
1800' of 1" Cable; = 1,800
2500' of 1-1/8" Cable; W = 2.28; 1-12d = -.1/8; L_1 = 3,075
900' of 1-1/4" Cable; W = 2.81; 1-12d = - 1/4; L_1 = 1,321
7,000 Feet tapered cable; Effective Length = 7,628 Feet

Target Drag = D = 27,300 Pounds (From Figure 23)

$\frac{D}{L_1} = 3.58$

Cable Angle at target, φ, = 37 Degrees (From Figure 32)
Cable Load = 27,300 x tan 37° = 20,600 pounds
Cable Tension at Target = 27,300 x sec 37° = 34,200 pounds

Drag of Cables

1800 x 6.8 = 12,240 (From Figure 7)
1800 x 7.5 = 13,500
2500 x 8.6 = 21,500
900 x 9.9 = 8,900
Drag of Towline 7,000 Feet = 56,140 Pounds

Horizontal Drag at Towing Vessel = 27,300 + 56,140 = 83,440 Pounds
(Virtually maximum cable tension)

Increase in cable tension along the towline = 7.04 pounds per foot.

Note: The horizontal drag of 83,440 pounds can be roughly checked by converting the wetted areas of the tapered towline to a length of 1 inch constant diameter cable with the same wetted area. In respect to wetted area the tapered towline corresponds to 7,300 feet of 1 inch cable, which in Figure 23 gives a horizontal drag at the towing vessel of 83,000 pounds.

APPENDIX 2

Maneuverability of Towing Targets

Steering the Target

Since a towing target is steered by its towline it is essential that the forward sections of the hull can swing quickly towards a new direction of the towline. The forward sections must, therefore, be specifically designed for this purpose, and the towline attached forward of the effective center of the lateral plane. The farther forward the towpoint is located, the more leverage the towline will have in swinging or skidding the bow towards a new direction; however, the cable load will have a greater tendency to depress the bow. This makes the towing target more reluctant to turn, and may produce a negative trim, which will most certainly result in a casualty with a planing craft.

Therefore, the larger the cable load, the farther aft the towpoint must be located. With an excessive cable load the safest location is obviously the longitudinal center of flotation, which should be close to the high speed center of dynamic pressures, so that the cable load cannot produce negative trim angles at either low or high speeds.

In the G-60 design directional stability is secured by towing with a bridle attached to the chines, so that the cable load appears to be equally distributed between the two sides of the hull when the target travels on a straight course. But turning the target through the bridle, when the latter makes a large angle with the keel-line, will shift the cable load towards the outside chine. As the target will tend to turn to that side which is most heavily loaded, some of the qualities of the bridle in furthering directional stability when the cable angle is small, may have detrimental effects on the steering when the cable angle is large.

Inasmuch as the cable-carrier reduces the cable load and the cable angle to small values it will considerably benefit the maneuverability of the G-60 target.

Turning the Targets

Figure 8 shows a simple 90-degree turn to starboard, with the towing vessel turning on a radius of 1,000 feet at 30 knots. The target is being towed by 7,000 feet of towline. The path of the towing vessel is divided into 10-second increments, so that its position along the path is known at a certain time.

Due to the Magnus effect produced by the lay of the strands in the cable and the sidewise motion of the cable through the water, the cable will rise towards the surface during a starboard turn, and sink towards the bottom when turning to port. In a starboard turn the towline will tend to assume a position tangential to the path of the target. Assuming this to be a straight line, the approximate path of the target is easily visualized, and its speed can be illustrated by the position of the towing vessel at the 10-second increments.

The towing vessel can turn 60 degrees without causing any appreciable change in either direction or speed of the target. At this angle that portion of the towline nearest the towing vessel has already undergone a sidewise movement, so that the Magnus effect will from the beginning of the turn carry part of the cable weight, thereby reducing the cable angle and load. Consequently, when making a turn to starboard the towing vessel can safely make the first 60 degrees with a short turning radius, say 1,000 feet.

During the next time intervals the target will suddenly decelerate to about 4 knots and thereafter accelerate to 30 knots, uniformly, but far too quickly. As these changes of speed may produce tensions exceeding the yield strength of the cable, the path and the speed of the towing vessel should be modified to produce a uniform speed of the target. The towing vessel should, therefore, enter the turn with a speed well below its maximum speed so that, at the time when the target decelerates, the towing vessel can counteract, either by accelerating or by expanding the turning radius, or by doing both.

Figure 9 shows a 180-degree turn with and without a cable-carrier. Without cable-carrier the target maintains a uniform speed of about 10 knots during the turn. The turning procedure is:

1. Slow down to 10 knots before entering the turn.
2. Turn 60 degrees with a small turning radius, say 1,000 feet.
3. Expand the turning radius to the length of towline and accelerate quickly to 30 knots.
4. Reverse the turn at 230 degrees until both the towing vessel and the target have completed the 180 degree turn.

Examining Figure 9 it is seen that the sidewise speed of the cable producing the Magnus effect is high up to the 500-second increment, at which time the turn has practically been completed, and the target has accelerated to a higher speed which improves its maneuverability. The dangerous part of the turn, during which the target speed is low and the target is steered by the cable (the G-60 target through the port leg of the bridle) is, therefore, made with both a small cable angle and cable load, each reduced by the Magnus effect. When this effect ceases, at the 550-second increment, and the entire cable load of 20,300 pounds is again imposed upon the bridle, the target is traveling on a straight course, where the load should be equally distributed between the two sides.

To recapitulate: The principal features of this method of turning are,

a. the target speed is practically uniform during the turn,
b. the Magnus effect is produced from the very beginning by starting the turn with a small turning radius,
c. and the turn and the acceleration of the target to its maximum speed, are practically completed while the Magnus effect is still active.

The procedure for turning described above was for a straightaway target speed of 30 knots. If the maximum target speed is, for instance, 20 knots, the procedure would be the same with the exception of 4, which would read: Reverse turn at 230 degrees and decelerate uniformly to 20 knots until both towing vessel and target have completed the 180 degree turn.

A 90-degree turn is obviously started in the same manner, but the reverse turn is made at 140 degrees.

In Figure 9 the towline is shown as a straight line from the target to the towing vessel, when no cable carrier is used. But when employing a cable-carrier the latter will tend to follow the path of the towing vessel and in so doing will pull the target into a path having a radius larger than that which would be obtained without a cable carrier and closer to the path of the towing vessel. The speed of the target will, therefore, be increased to about 15 knots. The increased turning speed of the target will improve its maneuverability, and also reduce the change in cable tensions at the time when the target is accelerated to its original towing speed. The bend in the towline resulting from the sweep of the cable-carrier will have a damping effect on the overall cable tensions during the turn.

As the cable-carrier increases the turning speed of the target from 10 knots to about 15 knots, procedure 1 of this method of turning should be changed to;

1. Slow down to 15 knots before entering the turn.

It is concluded that the stability and maneuverability of a target during turns would be much improved by the use of a cable-carrier, and the time consumed in turning somewhat reduced.

APPENDIX 3

Comparison of Target Drags, Cable Angles, Loads, etc

Comparisons of target drags, cable angles, loads, maximum tensions, and cable material, for the targets mentioned in this report, are given in the following tables. The comparisons are based on a target speed of 30 knots and a towline length of 7,000 feet. Comparisons between tables show the improved towing characteristics to be expected from adoption of the proposed methods of towing.

Conventional Constant Diameter Towline

	Target Drag	Cable Angle	Cable Load	Maximum Cable Tension	Cable Material
G-60	33,000 lbs	45°	33,000 lbs	119,000 lbs	25,100 lbs
TMB-60 BuShips (A)	19,000 lbs	64°	39,000 lbs	101,000 lbs	25,100 lbs

Tapered Towline

	Target Drag	Cable Angle	Cable Load	Maximum Cable Tension	Cable Material
G-60	27,300 lbs	37°	20,600 lbs	83,400 lbs	14,500 lbs
TMB-60 BuShips (A)	13,100 lbs	59°	21,800 lbs	71,300 lbs	12,600 lbs

Tapered Towline Supported By Cable-Carrier

	Target Drag	Cable Angle	Cable Load	Maximum Cable Tension	Cable Material
G-60	22,100 lbs	6°	2,200 lbs	72,600 lbs	12,200 lbs
TMB-60 BuShips (A)	9,500 lbs	8°	1,400 lbs	50,800 lbs	7,600 lbs
TMB-50	Estimated 5,000 lbs	9°	800 lbs	39,800 lbs	5,300 lbs

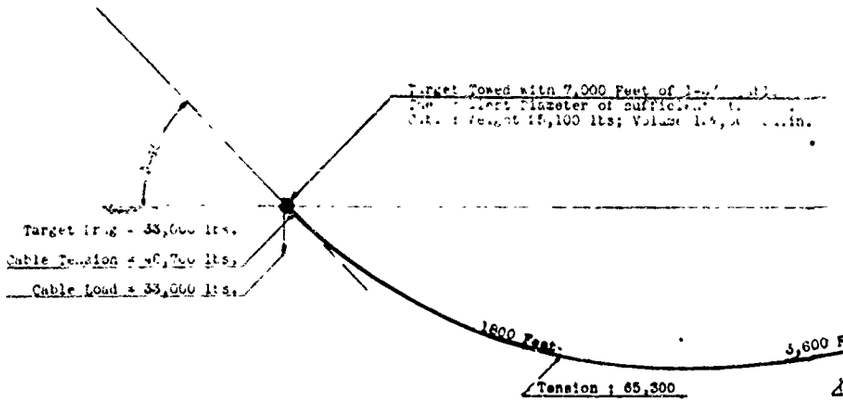


Figure 1a

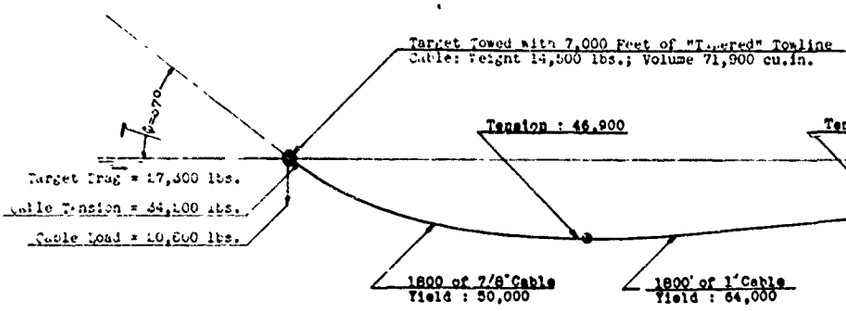


Figure 1b

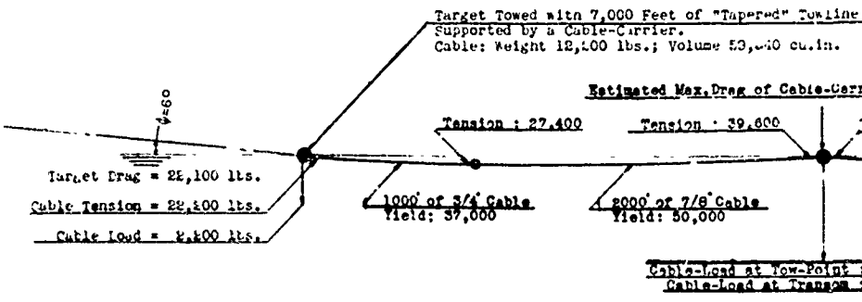


Figure 1c

FIGURE 1 - COMPARISON OF CABLE LOADS AND CABLE TENSIO
METHODS OF TOWING G-60 SLED-TYPE TARGET - SPEE

Figure 1a shows the present method of towing the target with a cable
constant diameter.

Figure 1b illustrates a proposed method in which the size of the cab
is varied in accordance with the tensions along the length of the c

Figure 1c illustrates a proposed method in which the size of the cabl
varied but in addition employs a cable-carrier.

The comparative cable sizes, sectional length, yield strength, loads,
and angle at the target, are estimated for a target displacement of
pounds, and a total length of 7,000 feet of towline.

A

...in.

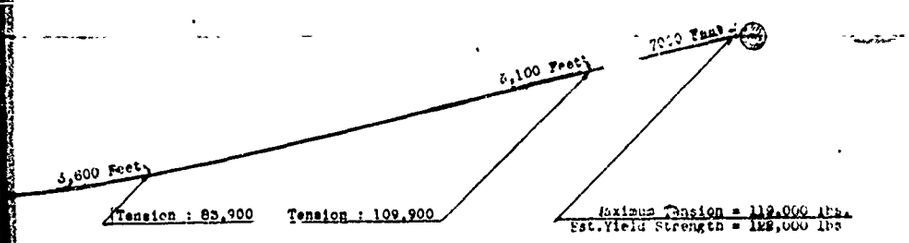


Figure 1a

" Towline
cu.in.

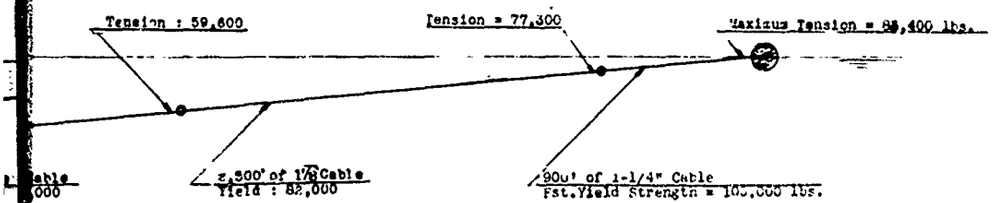
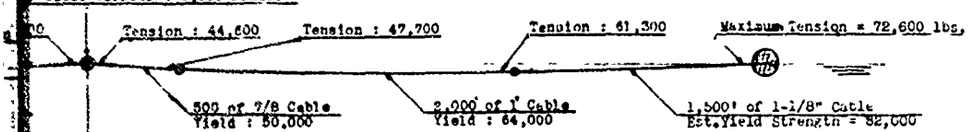


Figure 1b

d" Towline
0 cu.in.

Cable-Carrier : 5,000 Pounds



Tow-Point : 3,900 Pounds
t Transom : 2,100 Pounds

Figure 1c

BLE LOADS AND CABLE TENSIONS FOR THREE SLED-TYPE TARGET - SPEED 30 KNOTS

thod of towing the target with a cable of

ed method in which the size of the cable
the tensions along the length of the cable.

ed method in which the size of the cable is also
a cable-carrier.

sectional length, yield strength, loads, tensions,
stimated for a target displacement of 150,000
7,000 feet of towline.

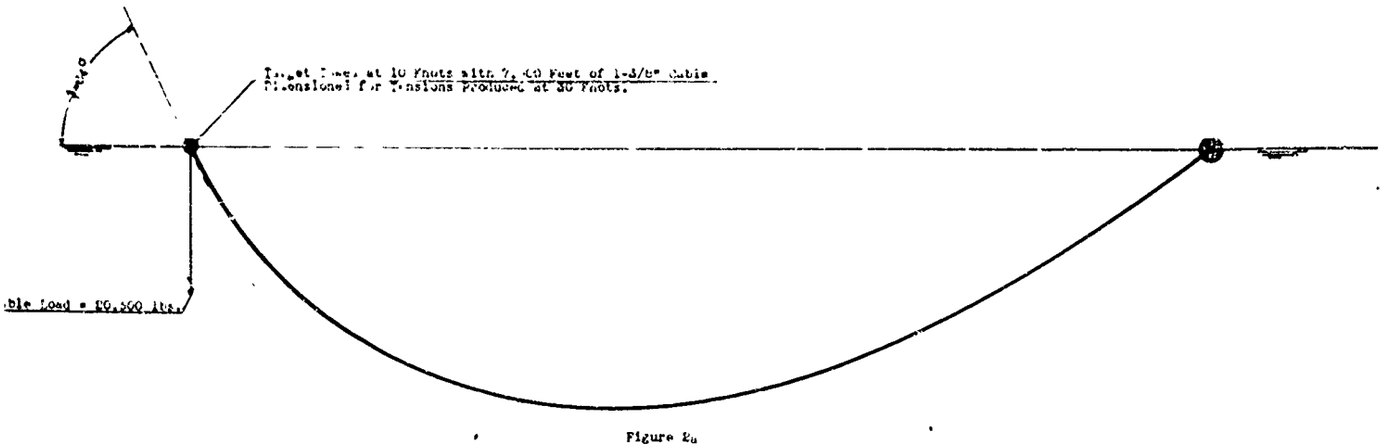


Figure 2a

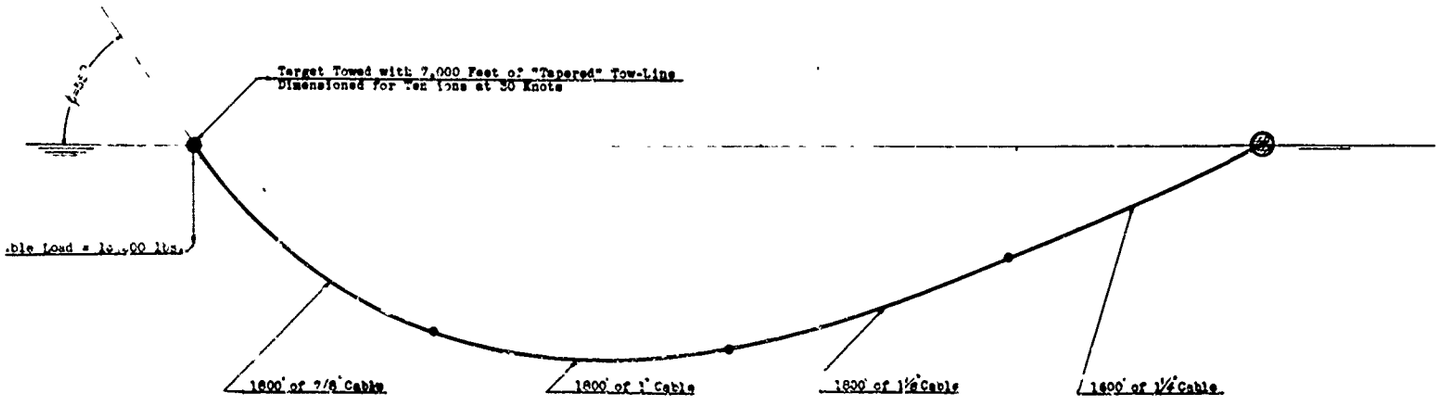


Figure 2b

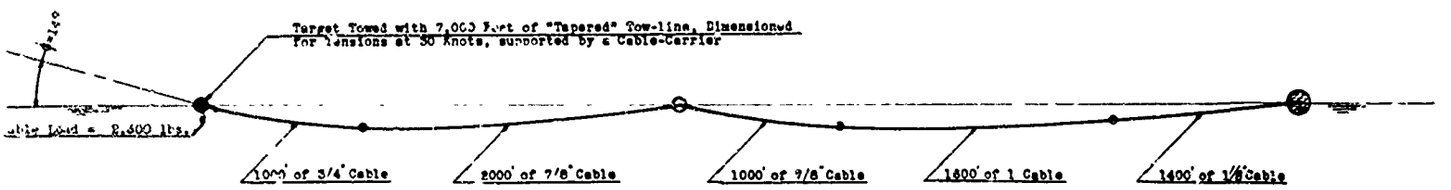


Figure 2c

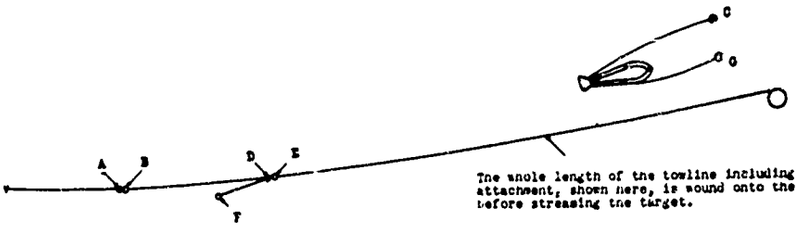
FIGURE 2 - COMPARISON OF CABLE LOADS FOR THREE METHODS OF TOWING G-60 SLED-TYPE TARGET - SPEED 10 KNOTS

Figure 2a shows the present method of towing the target with a cable of constant diameter.

Figure 2b illustrates a proposed method in which the size of the cable is varied in accordance with the tensions along the length of the towline.

Figure 2c illustrates a proposed method in which the size of the cable is also varied but in addition employs a cable-carrier.

The comparative cable sizes, sectional length, yield strength, loads, tensions, and [illegible] at the target, are estimated for a target displacement of 150,000 pounds, and a total length of 7,000 feet of towline.

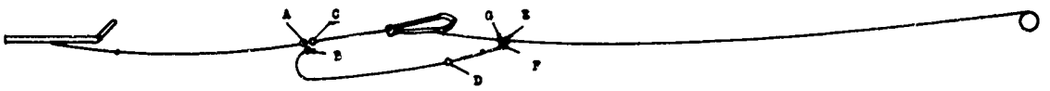


The whole length of the towline including the cable-carrier attachment, shown here, is wound onto the drum of the winch before streaming the target.

"Streaming" the Target with the Cable-Carrier.

The cable-carrier is towed by its bow-painter (G) behind the towing vessel. The stern-painter (C) is also onboard the towing vessel.

1. The target towline is let out in the usual manner until A-B appears.
2. Attach C to A and ease out until D-E, with line F, appears.
3. Anchor F and ease out until D-E is slack.
4. Detach E from D and attach G to E.
5. Haul in until F is slack and attach F to E.
6. Let out all.

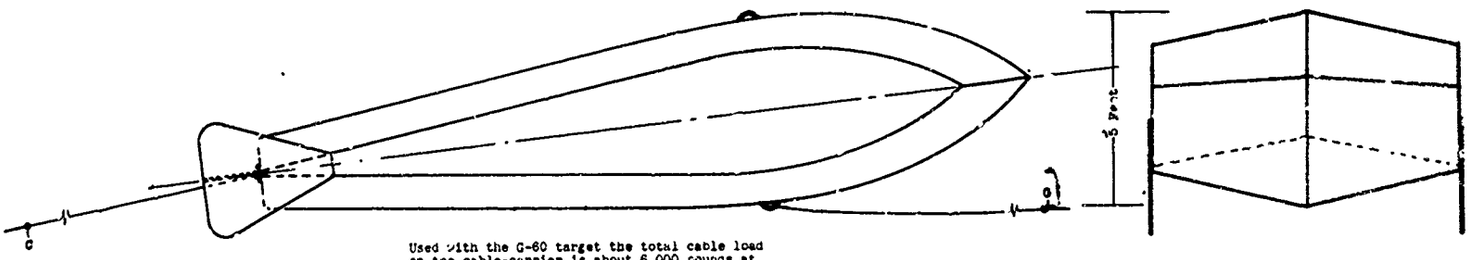


"Retrieving" the Target with the Cable-Carrier.

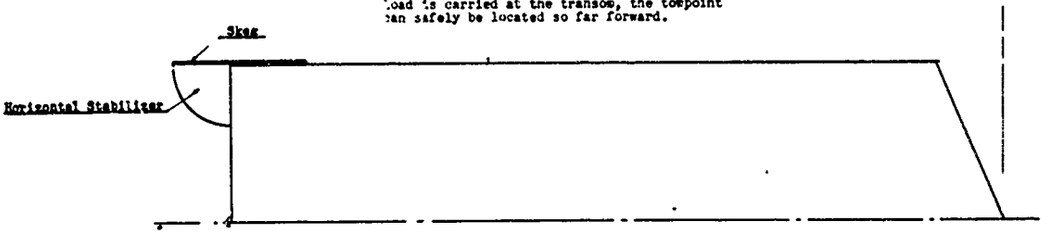
1. Haul in until G-E-F appears. Detach F from E and anchor F.
2. Ease out until target is towed by F. Detach G from E and attach E to D.
3. Haul in (free F when slack) until A-B-C appears and detach C from A.
4. Haul in all.

(During the "retrieving", the target towline will probably foul the skegs of the cable-carrier. The "retrieving" should, however, be continued without interruption, and the cable-carrier will soon free itself, by turning over on its back, in which position it travels equally well.)

Figure 3b



Used with the G-60 target the total cable load on the cable-carrier is about 6,000 pounds at all speeds. Since more than one third of this load is carried at the transom, the towpoint can safely be located so far forward.



The small size of the 50-foot cable-carrier is compensated by its ability to travel through breakers, or to nose upward with a large lift-drag ratio, should it momentarily become submerged. The reluctancy of the cables to be swished up and down in the water will dampen pitching in heavy weather. The hull is symetrical both in the vertical and the lateral planes, and all its surfaces are developable from flat plates.

Displacement Submerged = 25,600 Pounds
Weight = 8,000 Pounds
Length of Hull proper = 20 Feet
Constant Beam = 6 Feet
Designed Trim = 1/2-Degree by Stern

Figure 3a

FIGURE 3 - TMB CABLE-CARRIER AND METHOD OF STREAMING AND RETRIEVING THE TARGET

Figure 3a shows the TMB-Design of Cable-Carrier

Figure 3b illustrates a method of Streaming and Retrieving the target

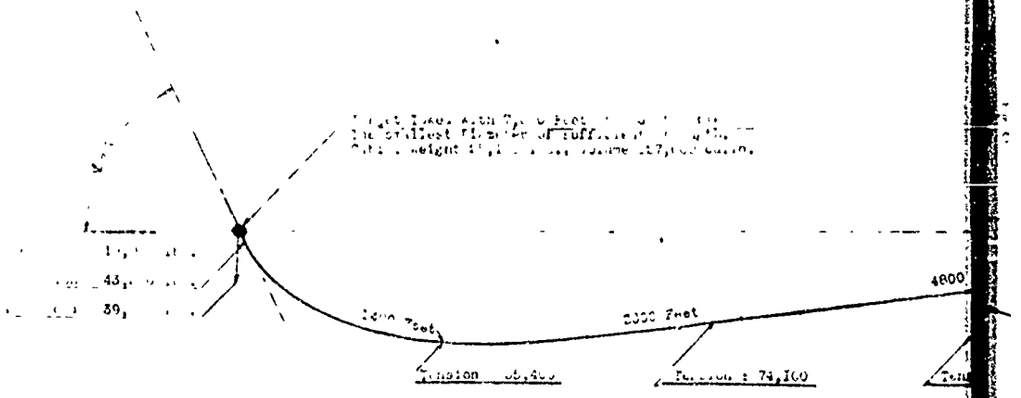


Figure 4a

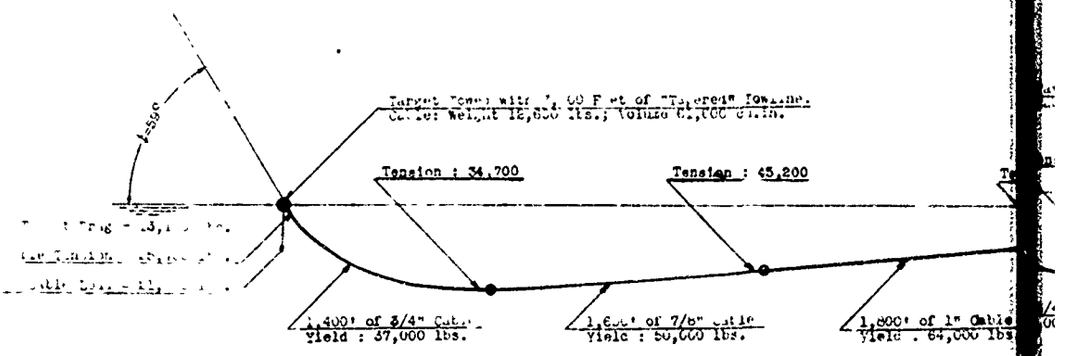


Figure 4b

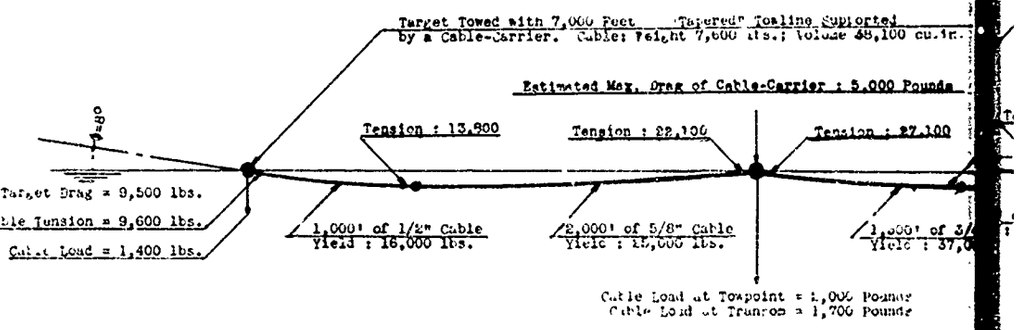


Figure 4c

FIGURE 4 - COMPARISON OF CABLE LOADS AND CABLE TENSIONS FO
BUSHIPS' DESIGN A AND TMB'S DESIGN 60 TARGET -

Figure 4a shows the present method of towing the target with a c
constant diameter.

Figure 4b illustrates a proposed method in which the size of the
is varied in accordance with the tensions along the length of th

Figure 4c illustrates a proposed method in which the size of the
also varied but in addition employs a cable-carrier.

The comparative cable sizes, sectional length, yield strength, l
tensions, and angle at the target, are estimated fo. a target dr
ment of 75,000 pounds, and a total length of 7,000 feet of towli

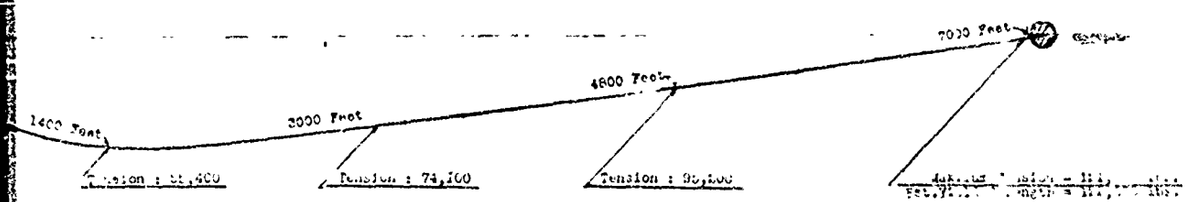


Figure 4a

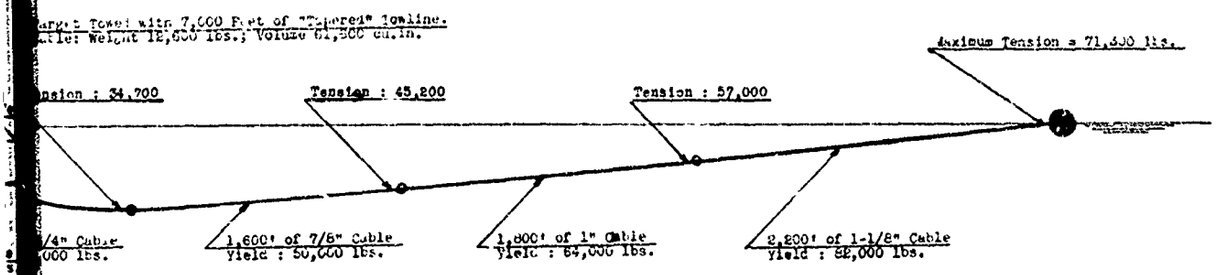


Figure 4b

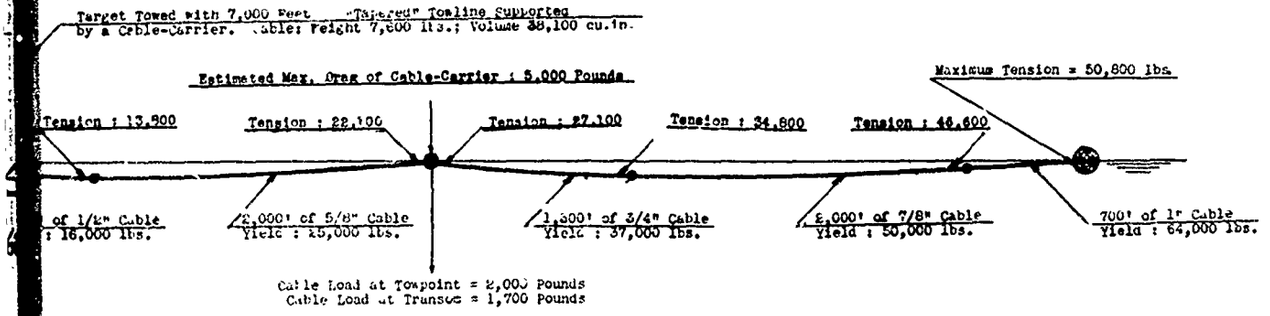


Figure 4c

PARISON OF CABLE LOADS AND CABLE TENSIONS FOR THREE METHODS OF TOWING IPS' DESIGN A AND TMB'S DESIGN 60 TARGET - SPEED 30 KNOTS

Figure 4a shows the present method of towing the target with a cable of constant diameter.

Figure 4b illustrates a proposed method in which the size of the cable is varied in accordance with the tensions along the length of the towline.

Figure 4c illustrates a proposed method in which the size of the cable is also varied but in addition employs a cable-carrier.

The comparative cable sizes, sectional length, yield strength, loads, tensions, and angle at the target, are estimated for a target displacement of 75,000 pounds, and a total length of 7,000 feet of towline.

B

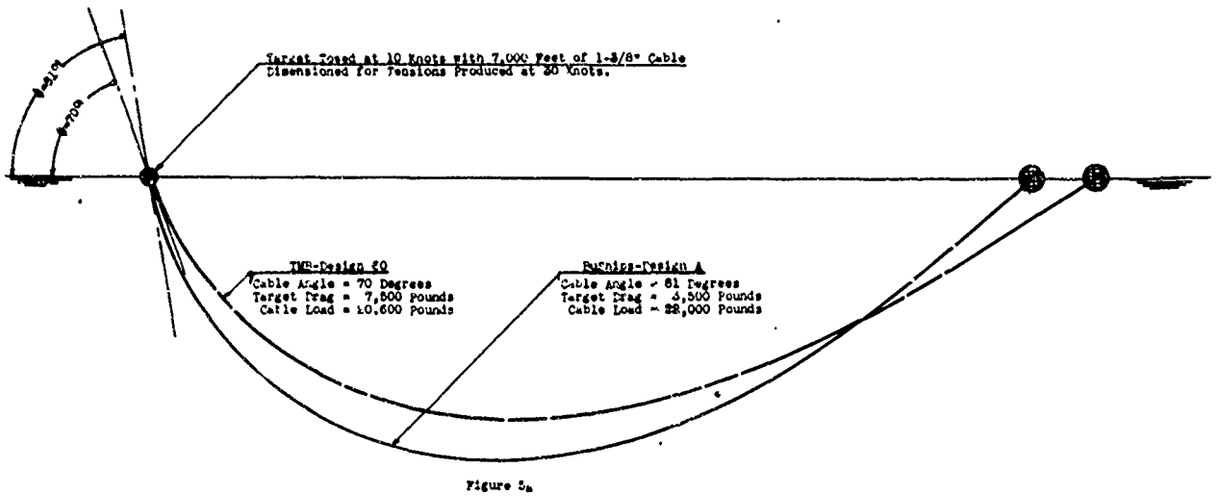


Figure 5a

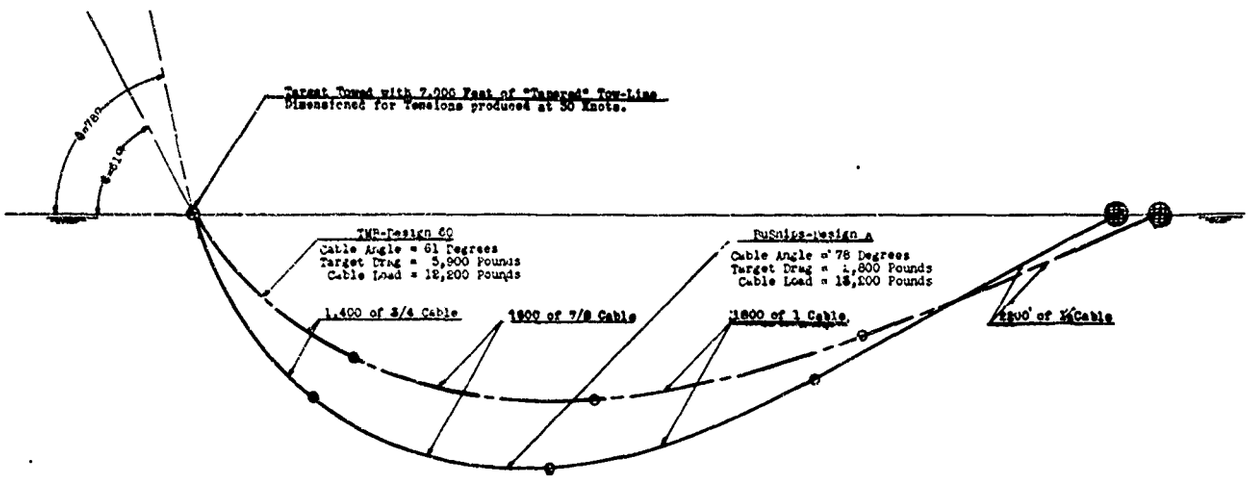


Figure 5b

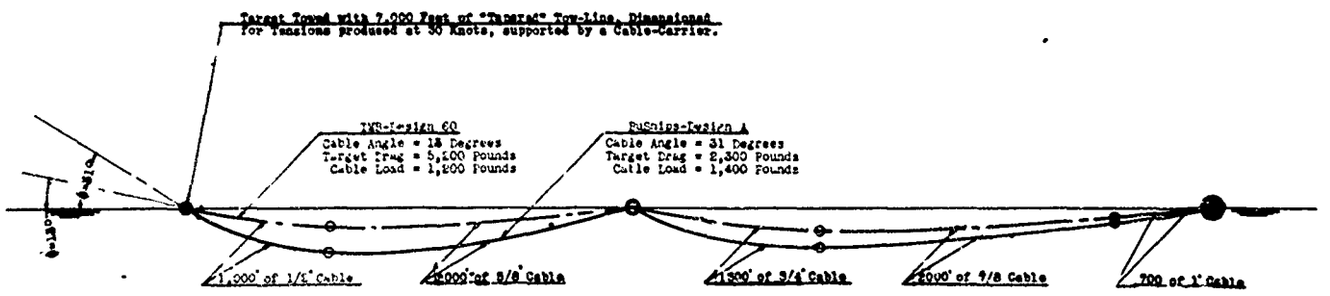


Figure 5c

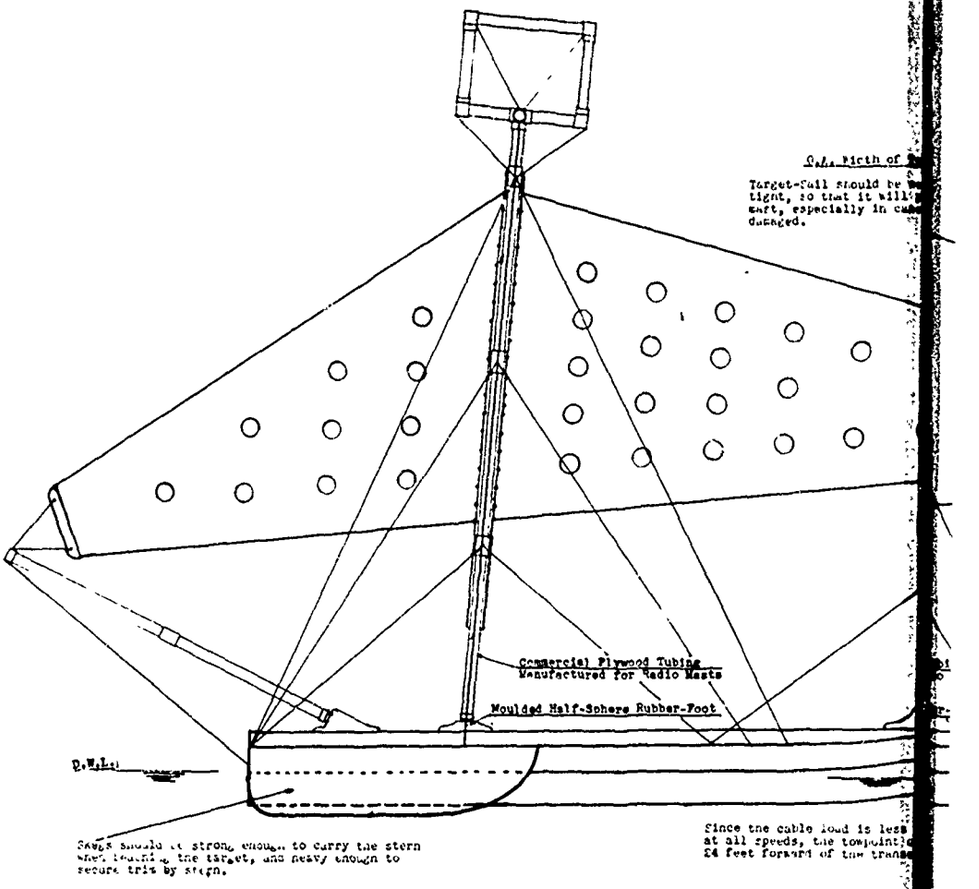
FIGURE 5 - COMPARISON OF CABLE LOADS FOR THREE METHODS OF TOWING BUSHIPS' DESIGN A AND TMB'S DESIGN 60 TARGETS - SPEED 10 KNOTS

Figure 5a shows the present method of towing the target with a cable of constant diameter.

Figure 5b illustrates a proposed method in which the size of the cable is varied in accordance with the tensions along the length of the towline.

Figure 5c illustrates a proposed method in which the size of the cable is also varied but in addition employs a cable-carrier.

The comparative cable sizes, sectional length, yield strength, loads, tensions, and angle at the target, are estimated for a target displacement of 75,000 pounds, and a total length of 7,000 feet of towline.



O.A. Length = 50 Feet
Constant Beam = 16 Feet
Displacement = 30,000 Pounds
Designed Trim = 1/2 Degree by Stern

Figure 6.

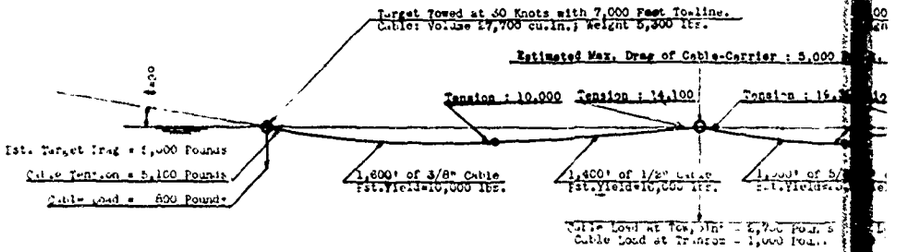


Figure 6:

FIGURE 6 - THE TMB-50 TARGET DESIGN, WITH CABLE LOAD

Figure 6, shows the TMB-design of a 50-foot tar

Figure 6b shows the values of cable an
maximum tension when the target is towed at 30
with 7,000 feet of towline.

A

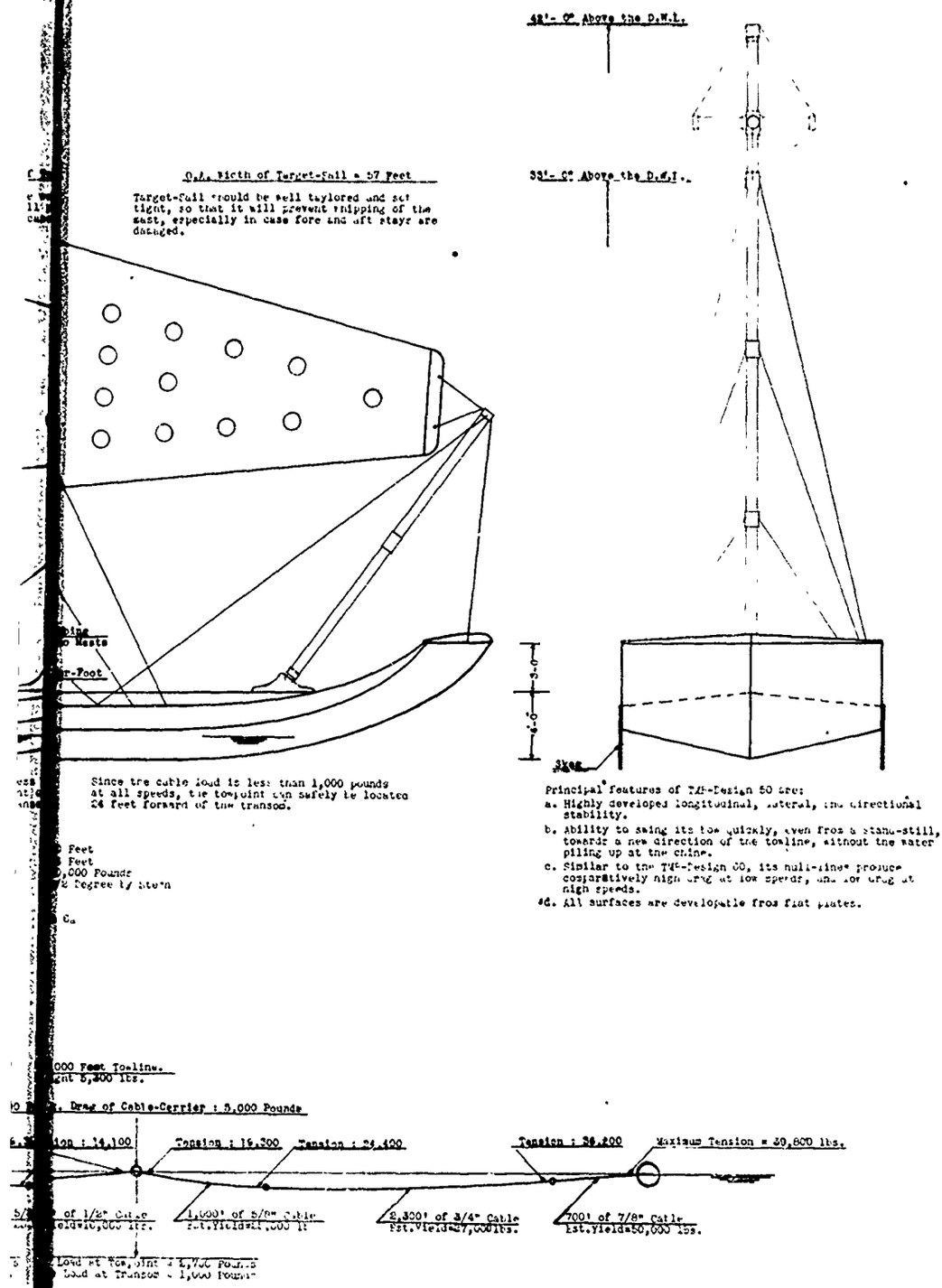


Figure 6b

DAD ESIGN, WITH CABLE LOAD AND TENSIONS AT 30 KNOTS

s the TMB-Design of a 50-foot target.

s the values of cable angle, load, and on when the target is towed at 30 knots t of towline.

B

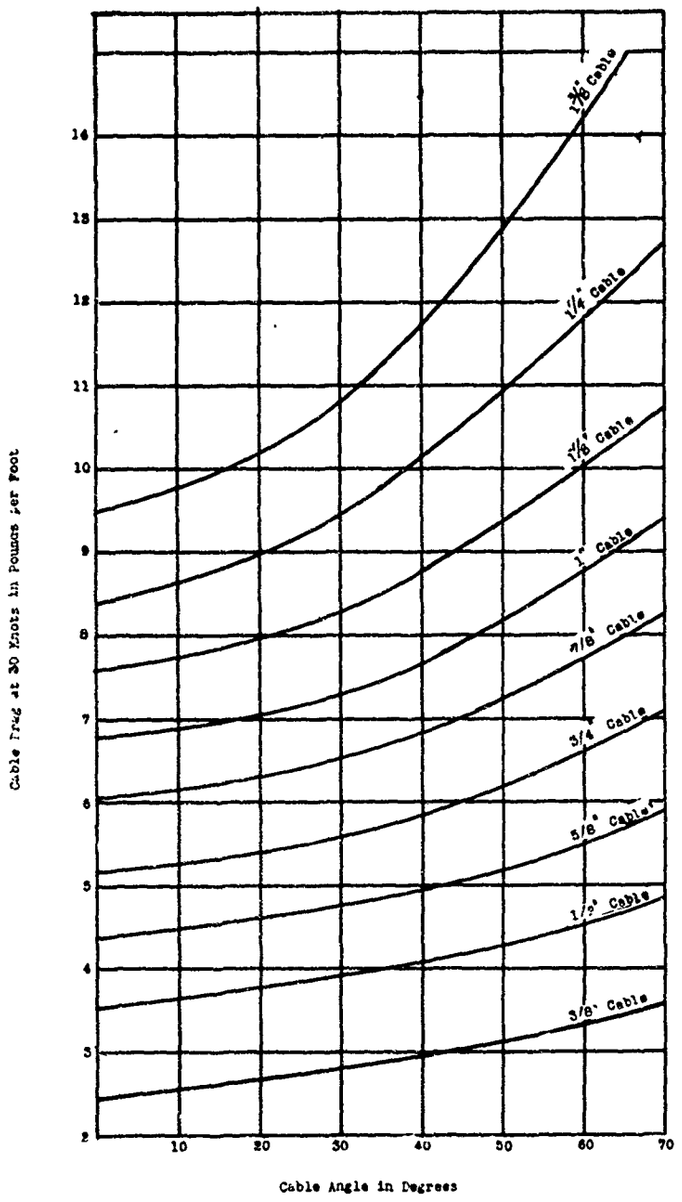


FIGURE 7 - ESTIMATED DRAG OF DIFFERENT CABLE SIZES VERSUS CABLE ANGLE

The cable Drag at zero degree is given by $\frac{1.6}{50} * \frac{\rho}{g} * d * V^2$, Appendix 1.

The increase of cable drag with increase of cable angle is found by empirical methods.

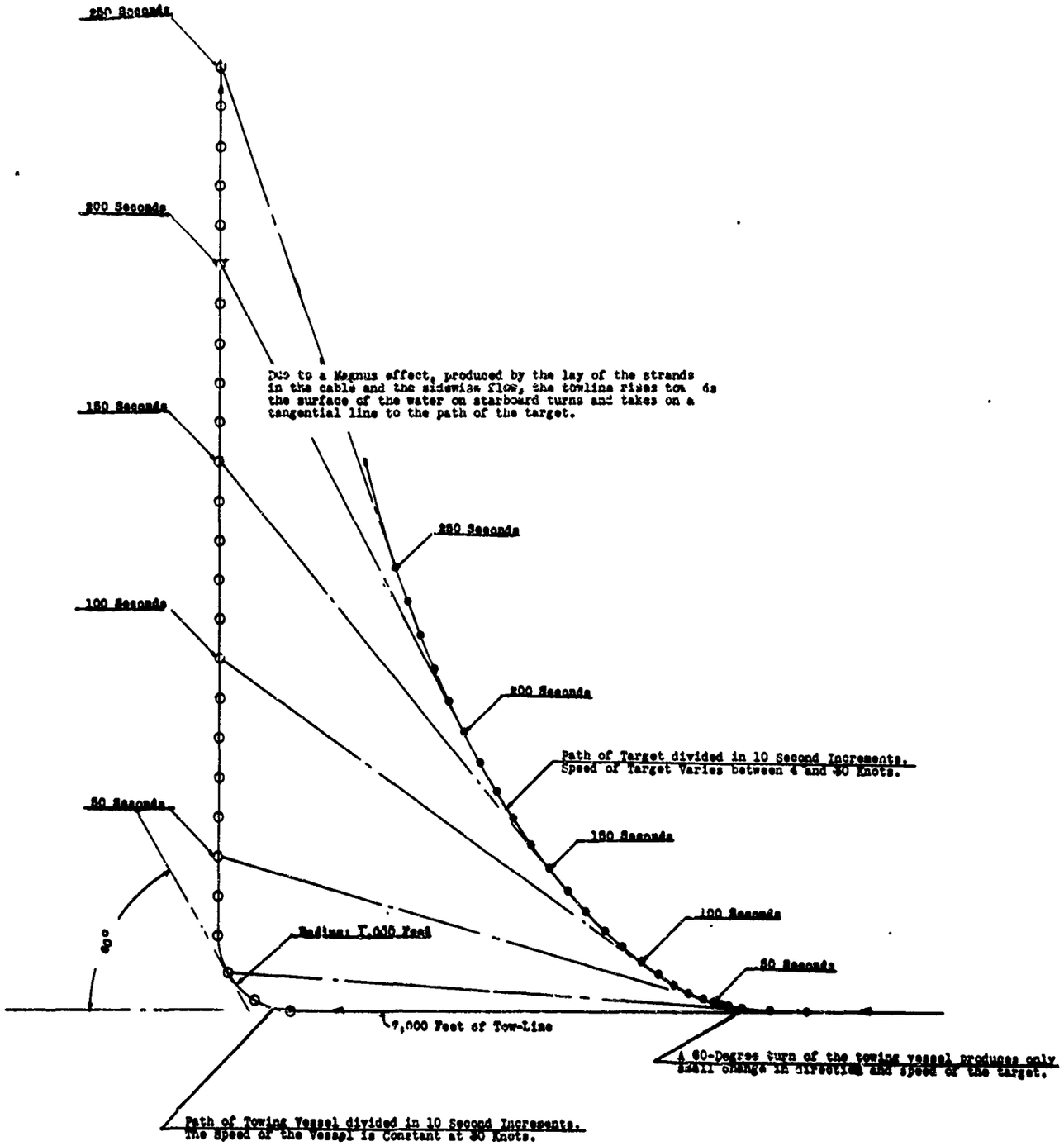


FIGURE 8 - SCHEMATIC SKETCH SHOWING PATH AND SPEEDS OF A TARGET TOWED BY A VESSEL MAKING A 90-DEGREE TURN AT 30 KNOTS

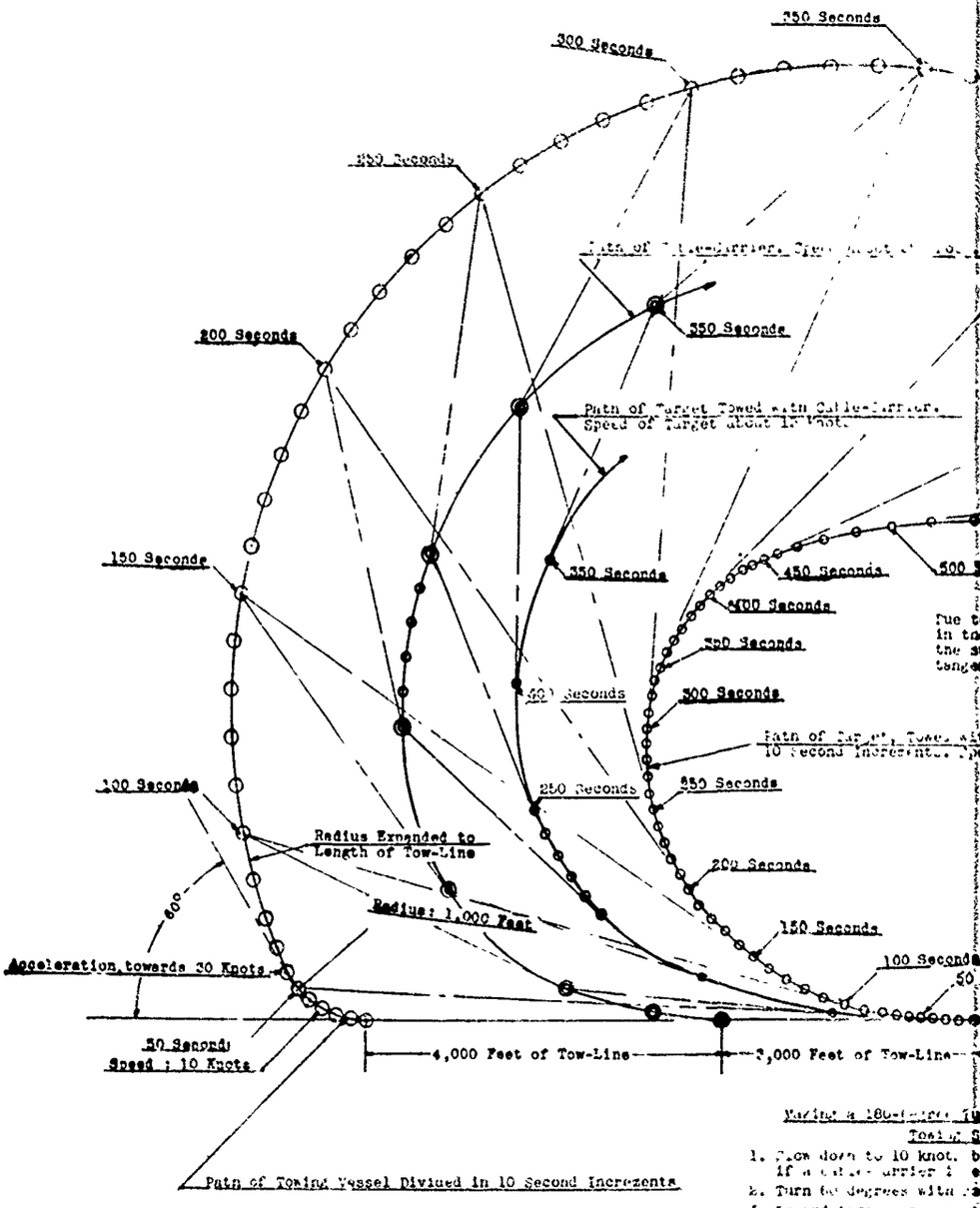
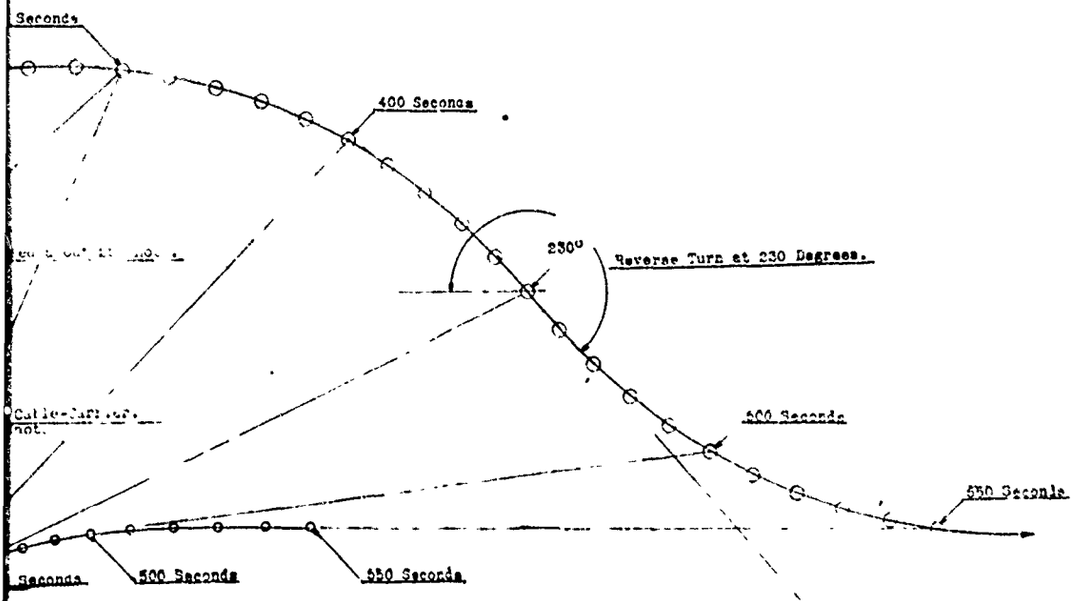
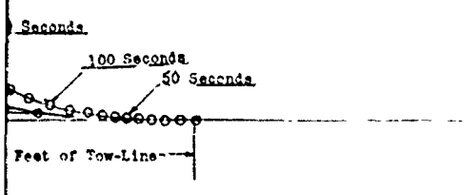


FIGURE 9 - SCHEMATIC SKETCH SHOWI[illegible] A METHOD [illegible]
WITH AND WITHOUT A CABLE



Due to a Magnus effect, produced by the lay of the strands in the cable and the sidewise flow, the towline rises toward the surface of the water on starboard turns and takes on a tangential line to the path of the target.

of Target, Towed without Cable-Carrier, dividing it cond Increments. Speed of Target about 10 Knots.



The principal features of this method of turning are,

a. the target speed is practically uniform during the turn,
b. the Magnus effect is produced from the very beginning by starting the turn with a small turning radius,
c. and the turn and the acceleration of the target to its maximum speed, are practically completed while the Magnus effect is still active.

ing a 180-degree Turn within 10 Minutes.

Towing Speed 30 Knots.

n down to 10 knots before entering the turn (to 15 knots n Cable-Carrier is employed)
h 60 degrees with small radius, say, 1,000 feet.
and turning radius to length of towline and accelerate ckly to 30 knots.
erse turn at 230 degrees.

Towing Speed 20 Knots.

1, 2, and 3 same as above.
erse turn at 230 degrees and decelerate to 20 knots.

G A METHOD OF MAKING A 180-DEGREE TURN

HOUT A CABLE-CARRIER

B

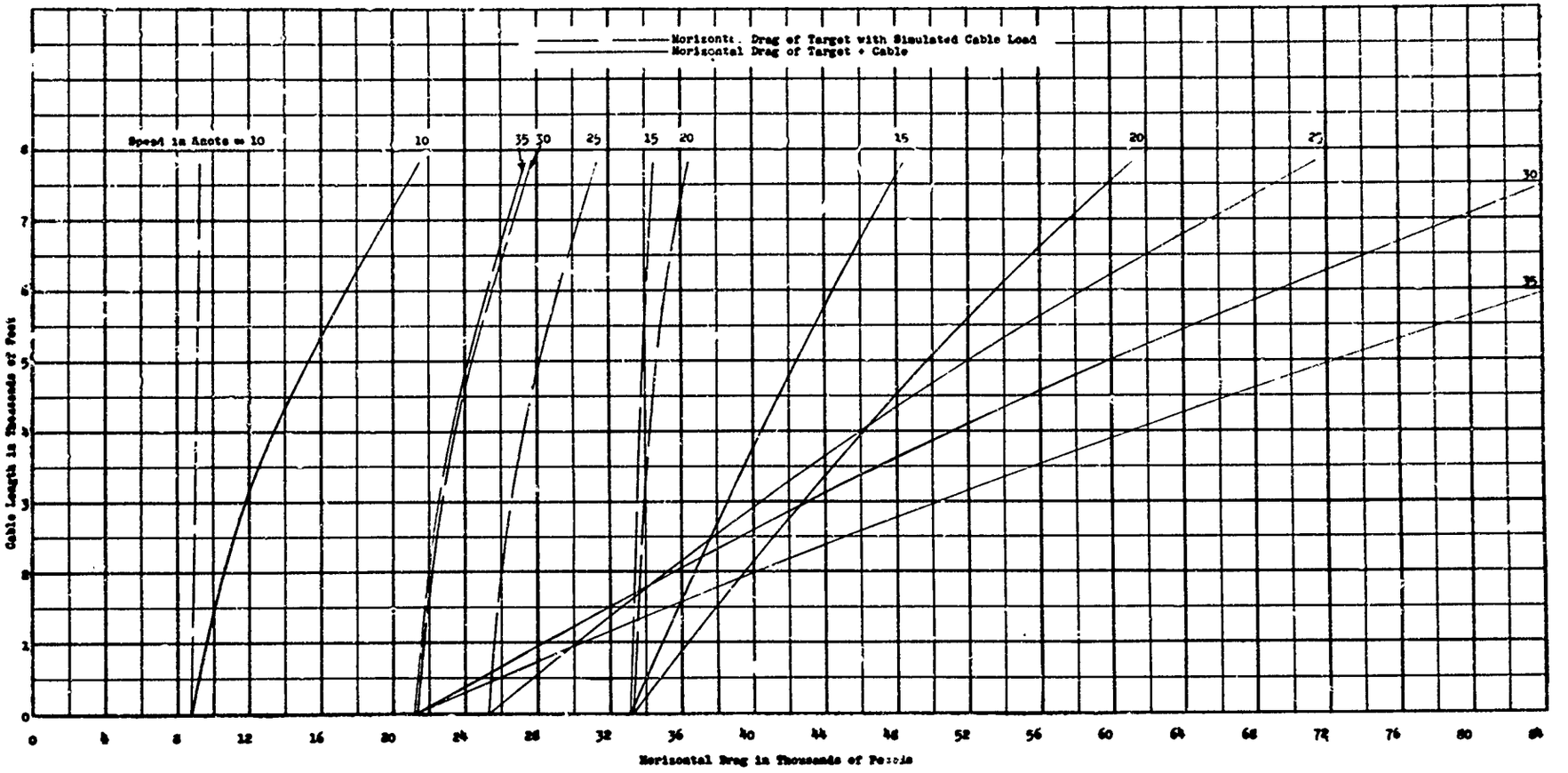


Figure 23 - Revised 0-60 Sled-Type Target Represented by Model 4024. Estimated Variation of Horizontal Drag of Target with Simulated Cable Load, and Horizontal Drag of Target + Cable, with Speed and Cable Length; Initial Trim = 8.8 Feet by Stern; Initial Displacement = 150,000 Pounds; Tow Point = 28.0 Feet Forward of Stern

Note - The curves are based on model data at the condition that gives minimum drag at a speed corresponding to 30 knots.

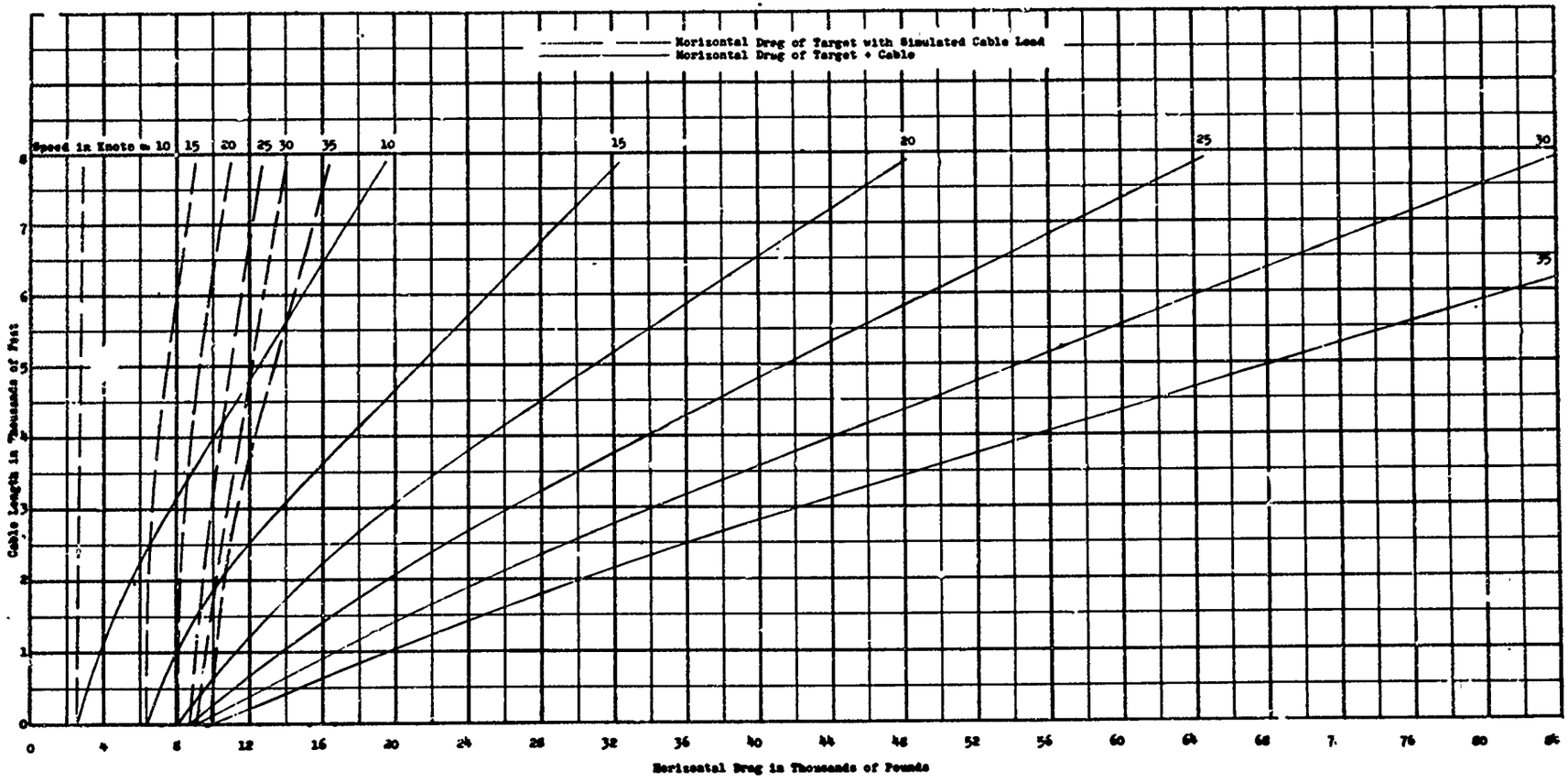


Figure 26 - Buffalo Design 'A' Boat-Type Target Represented by Model 4026. Estimated Variation of Horizontal Drag of Target with Simulated Cable Lead, and Horizontal Drag of Target + Cable, with Speed and Cable Length; Initial Trim = 1.3 Feet by Stern; Initial Displacement = 75,000 Pounds; Tow Point = 42.0 Feet Forward of Stern

Note - The curves are based on model data at the condition that gives minimum drag at a speed corresponding to 30 knots.

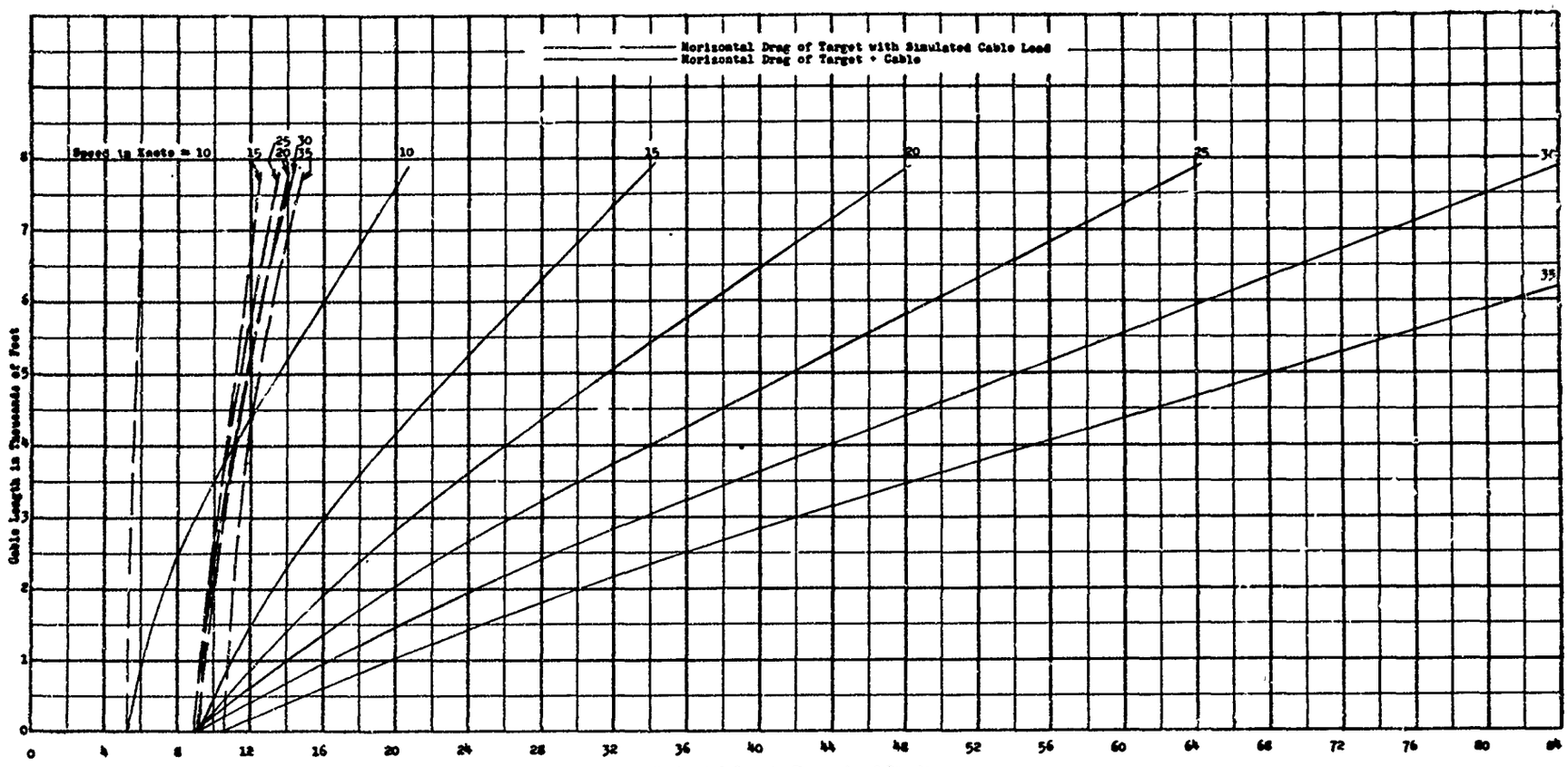


Figure 30 - THB Design Target Represented by Model 4029. Estimated Variation of Horizontal Drag of Target with Simulated Cable Load, and Horizontal Drag of Target + Cable, with Speed and Cable Length; Initial Trim = 1.7 Feet by Stern; Initial Displacement = 75,000 Pounds; Tow Point = 21.9 Feet Forward of Stern

Note - The curves are based on model data at the condition that gives minimum drag at a speed corresponding to 30 knots.

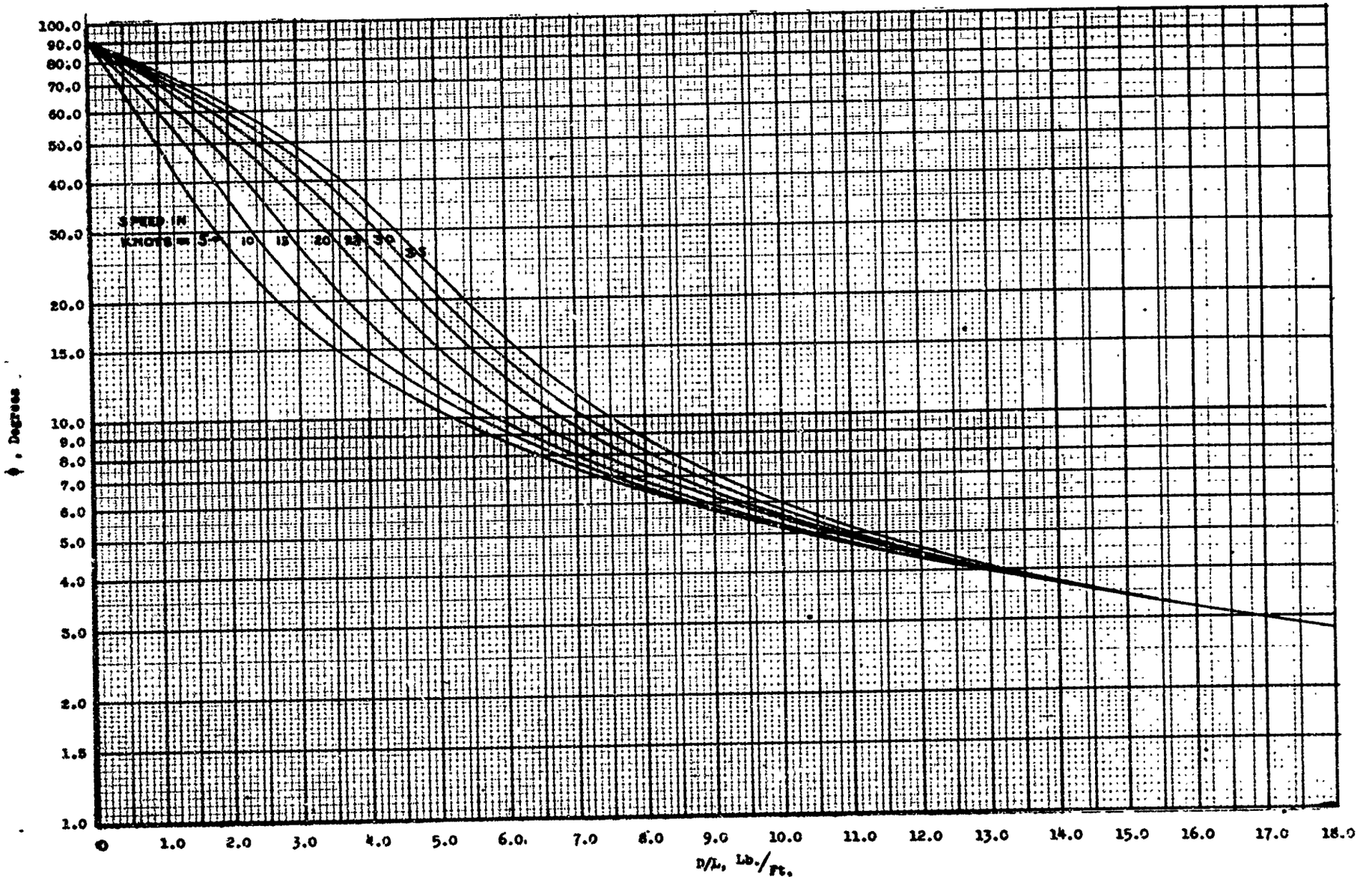


Figure 38- Characteristics of a 1" Stranded Wire Cable Submerged in Salt Water at 50° F with Each End Supported at the Surface. V = Speed of Advance in Knots; L = Cable Length in Feet; D = Superimposed Horizontal Target Drag at the Trailing End of the Cable in the Opposite Direction to V; ϕ = Angle of the Cable with the Horizontal at the Trailing End